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Semiconductor optical radiation source in which at least one of the two semiconductor regions has a hilly outer surface

The invention concerns a semiconductor optical radiation source comprising at least one pn junction between two regions of different types of conductivity.

It has already been discussed to reduce radiation loss due to total reflection in semiconductor optical radiation sources by embedding the semiconductor body in plastic, which has the effect of increasing the angle of total reflection and thus of improving radiation output. It should be noted, however, that semiconductor material has relatively high refractive indices; for example, the refractive index n of GaP is 3.3. The critical angle α of total reflection of such a material with respect to air is therefore correspondingly small, for example $\alpha = 17.7°$ for GaP. Thus, in the example cited, all radiation that strikes the semiconductor surface at an incident angle greater than α is totally reflected and can, at best, leave the crystal only after one or more total reflections. The radiation loss due to total reflection is therefore quite high. If an attempt is made to reduce this component by embedding the semiconductor crystal in plastic as mentioned above, the refractive indices of the plastics available for this purpose are no greater than 1.6. The resulting improvement is therefore slight.

It is already known (see *Physics of Semiconductor Devices*, John Wiley & Sons, New York, 1969, pp. 636-640) to realize semiconductor radiation sources in the form of hemispheres or half-paraboloids. This measure nearly suppresses total reflection of the radiation incident in the hemisphere or paraboloid, provided that the emitting surface is located at the center of the bottom surface of said hemisphere or paraboloid. Due to this limiting condition, less than 5% of the largest cross-sectional area of the sphere or paraboloid is available as radiation-emitting area. Because of this, and as a result of relatively strong absorption of the generated radiation due to the relatively long path it must travel inside the dome because of the dome dimensions, the radiation density on the surface of such semiconductor radiation sources is very low. Moreover, due to the aforesaid long path of the radiation inside the dome, this configuration cannot be used for semiconductor radiation sources made of semiconductor material, which strongly absorbs the generated radiation. Furthermore, the consumption of semiconductor material associated with such radiation sources is many times that

required for planar light-emitting diodes. Added to this is the fact that there is currently no practicable method for manufacturing such hemispherical or paraboloid semiconductor radiation sources economically in large quantities.

The object of the present invention is, therefore, to provide semiconductor optical radiation sources by means of which, simultaneously, total reflection losses are largely suppressed and efficient use is made of the material.

This object is achieved according to the invention in that at least one of the two semiconductor regions has a hilly outer surface.

With this measure, the external efficiency of a semiconductor radiation source realized in this manner is greatly increased over that of a semiconductor radiation source with a planar surface, by a factor of about 2.5 or, in particularly favorable embodiments, as much as 5. This increase in external efficiency derives from a reduction of the total reflection component, in some embodiments also from an increase in the percentage of emitting area, and in one other embodiment from a decrease in absorption losses brought about by a reduction of the dome dimensions and resultant shortening of the path of the radiation inside the dome. The reduction of the total reflection component comes about as follows: since, in semiconductor materials, the critical angle of total reflection with respect to air is small, those radiation directions that are totally reflected [sic] when the surface of the semiconductor radiation source has a planar configuration -- and this is a large percentage of the total radiation -- are given the opportunity by the hilly surface configuration to strike the surfaces of the hillocks at an incident angle that is smaller than the critical angle of total reflection. As a result, the fraction of radiation that is always totally reflected when the surface is planar now has some chance of exiting the surface. In addition, radiation components that are totally reflected one or more times at one hillock surface gain the opportunity of striking another hillock surface at a smaller angle than the critical angle of total reflection and thus of exiting the surface.

This improvement in the external efficiency of the semiconductor radiation source is automatically tied in with improved utilization of the semiconductor material.

An improvement of the invention is that the hillocks are realized as specific geometric, spatial figures. This measure provides the advantage that the total reflection losses associated with an emitting pn junction of a given size and position can be minimized.

It is also advantageous for the hillocks to have an approximately triangular cross section.

In addition, it is advantageous for the angle of the triangular cross section that is at the peaks of the hillocks to be approximately twice the critical angle of total reflection of the material forming the hillocks. This measure makes it possible to minimize total reflection losses for hillocks of triangular cross section and with a given position for the surface of the radiation-generating pn junction.

It is further advantageous for the hillocks to be pyramidal or conical in shape.

An improvement of the invention is that the hillocks have a circular or parabolic cross section.

A further development of the invention is that the hillocks are formed to be hemispherical or paraboloid. Such semiconductor surfaces can, in fact, be made, as Figs. 2 and 3 and the accompanying description show. This last-cited measure makes it feasible to eliminate total reflection losses practically completely if the emitting surface of the pn junction is located approximately at the center of the hemisphere or paraboloid. A semiconductor radiation source provided with hemispherically or paraboloidally shaped hillocks has the advantage of better utilization of material compared to a semiconductor radiation source of hemispherical or paraboloid shape and suitably larger size, and if the semiconductor material strongly absorbs the intrinsic radiation generated, the advantage of much lower intrinsic absorption, since the division of the semiconductor surface into many small hemispheres or half-paraboloids, as opposed to a single hemisphere or a single half-paraboloid, greatly diminishes the distance from the emitting surface to the surface of the semiconductor. In addition, a semiconductor radiation source provided with hemispherical or paraboloid hillocks is readily producible, as Figs. 2 and 3 and the corresponding parts of the description show, whereas it is has been difficult heretofore to make a substantially larger semiconductor radiation source in a hemispherical or paraboloid shape.

It is further advantageous in certain embodiments for the pn junction layers emitting the optical radiation to be disposed inside the hillock.

An improvement of the invention is that the radiation-generating pn junction layers are disposed in the upper third of each hillock. This measure offers advantages particularly for hillocks of triangular cross section, since, by this means, only a very small percentage of the radiation exiting a hillock strikes a second hillock and is able to make its way into that second hillock by refraction and absorption and thus give rise to a certain radiation loss due to secondary effects.

One improvement of the invention in connection with certain embodiments is that the pn junction layers emitting the radiation are disposed under the hillocks. For example, this arrangement of the emitting barrier layers is ideal in the case of hemispherical or semi-paraboloid hillocks.

It is further advantageous in some cases for the pn junction layers emitting the optical radiation to be narrower than the widest portions of the hillock. This measure is important primarily in regard to semiconductor radiation sources comprising hemispherical or paraboloid hillocks. However, it is also used from time to time in the case of hillocks of triangular cross section, for example when the radiation-emitting pn junction layers are disposed in the upper third of each hillock.

One improvement of the invention for certain embodiments is that the diameter of the pn junction layers is less than 30% of the smallest width of the hillocks concerned. This measure derives from certain optimization conditions for the external efficiency of semiconductor radiation sources comprising hillocks of hemispherical or parabolic cross section.

An improvement of the invention is that the pn junction layers emitting the optical radiation are disposed concentrically with the centers of the hillocks.

It is further advantageous that the hillocks form rows of hillocks.

An improvement of the invention is that the rows of hillocks extend in a wave-shaped or meander-shaped manner.

It is further advantageous for the valleys between the hillocks to be filled with a transparent medium that has a refractive index greater than 1.5. This measure, apart from the advantages of our invention, further makes use of the fact that the angle of total reflection is increased by embedding the hillocks in transparent plastic having the highest possible refractive index, thus bringing about an increase in the external efficiency of a semiconductor voltage [sic] source. The light output of a semiconductor radiation source with conically or pyramidally shaped hillocks can thereby be reduced by a factor of 5, compared to the light output of a similar but planar-surfaced semiconductor radiation source coated with the same plastic.

An improvement of the invention is a method of fabricating semiconductor optical radiation sources wherein arranged in a high-resistivity semiconductor body are plural parallel, stripe-shaped regions of one type of conductivity and, thereover and approximately perpendicularly thereto, plural parallel, stripe-shaped regions of a second type of conductivity opposite to the first type of conductivity, and in that [sic] the areas of intersection of the two regions of different types of conductivity come to be disposed under the centers of the hillocks.

The invention will be described in more detail hereinbelow with reference to the drawing.

Therein:

Figure 1 is a cross section of a semiconductor optical radiation source with a hilly outer surface on which the hillocks have a triangular cross section.

Figure 2 is a cross section of a semiconductor optical radiation source taken along line II-II of Fig. 3.

Figure 3 is a plan view of a high-resistivity semiconductor body comprising parallel, stripe-shaped regions of one type of conductivity, overlain perpendicularly by parallel, stripe-shaped regions of a second type of conductivity opposite to the first.

Figure 1 depicts a semiconductor body 1 in cross section. Reference numeral 2 denotes the region of the one type of conductivity. Reference numeral 3 denotes the region of the other type of conductivity, opposite to that of region 2. The contact 4 of region 2 is connected to symbolically indicated external connection 5. The contacts and connections of region 3 are not visible in the cross-sectional drawing. The radiation-emitting pn junction layers 6 are disposed in the upper third of each hillock. The angle at the peaks of the hillocks is denoted as 7.

Figure 2 illustrates a high-resistivity semiconductor body 10 in cross section. This high-resistivity semiconductor body 10 contains a netlike pattern of doping regions 11 associated with one type of conductivity and doping regions 12 associated with the other type of conductivity, opposite to that of regions 11. The contacts and connections of regions 11 and 12 are not visible in the cross section. The radiation-emitting pn junctions are denoted by 13. These are covered by hillocks 14 that have the shape of hemispheres or paraboloids. The size of the hillocks 14 is such that the width of a radiation-emitting pn junction 13 is equal to only one-third the base diameter of a hillock. As Fig. 2 shows, the radiation-emitting pn junctions are each disposed concentrically under the hillocks 14.

Figure 3 shows a plan view of the arrangement of Fig. 2 in which the hillocks 14 are realized as rotationally symmetrical. Deposited on a high-resistivity semiconductor body 10 is a grid of doping regions 11 of the one type of conductivity. Deposited perpendicularly thereto is a grid of doping regions 12 of the other type of conductivity, opposite to that doping regions 11. Doping regions 11 and 12 contact each other at the intersection points of the two grids. When a forward bias voltage is applied, light is generated only at these intersection points. Rising above the intersection points are hillocks 14, one of which is indicated by the dotted-and-dashed line in Fig. 3. Current is supplied to doping regions 11 and 12 via the external connections indicated by 16 and 17.

The invention is explained in further detail on the basis of the following exemplary embodiments.

First Exemplary Embodiment

The external efficiency of light-emitting diodes or alternatively of multilayered, radiation-emitting components, for example thyristors, can be increased by providing the external semiconductor surface with hillocks of roughly triangular cross section (see Fig. 1). Triangular hillock cross sections can be obtained, for example, by structural etching behind a mask and the choice of suitable crystal planes so that certain preferential directions are created for the etching-away of material. Another option for surface configuration would be the epitaxial growth of, for example, square islands formed by oxide masking. Specific hillock shapes can be obtained by the choice of suitable crystal planes and suitable crystal growth conditions. The bases of such hillocks are formed by semiconductor material of one type of conductivity, while the peaks of the hillocks are composed of semiconductor material of the other type of conductivity, opposite to that of the semiconductor material of the bases. If care is taken during the production of the hillocks to ensure that the angle at the peaks is twice as large as the critical angle of total reflection of the semiconductor material concerned, and also to ensure that the radiation-generating pn junction layers are disposed in the upper third of each hillock, the release of radiation from the semiconductor crystal can be optimized. The measure of situating the radiation-generating pn junction layer in the upper third of each hillock prevents secondary effects such as the re-entrance of radiation that has already left the crystal surface into a second hillock. To make the critical angle of total reflection as large as possible and thus to ensure the release of the largest possible percentage of the originally generated radiation, the valleys between the triangular hillocks are filled with a transparent plastic having the highest possible refractive index.

Second Exemplary Embodiment

The external surface of a semiconductor radiation source, such as a light-emitting diode or, alternatively, a thyristor, can comprise hillocks in the form of hemispheres or half-paraboloids for more favorable release of the radiation generated in the semiconductor (see Fig. 2). To this end, a network of doping stripes is deposited on a high-resistivity semiconductor body in such fashion that all the stripes extending parallel to one another have one type of conductivity, while all the stripes extending perpendicularly to the first-cited stripes and parallel to one another have the other type of conductivity, opposite to that of the first-mentioned stripes. A pn junction layer provided to generate radiation is thereby created at each intersection point of the differently doped stripes. The hillocks, represented by half-hillocks or half-paraboloids, are mounded over the pn junction layers in such a way that said layers lie roughly in the centers of the hillocks. The radiation generated therefore strikes the outer surface perpendicularly or roughly perpendicularly and can be released wholly or in large part to the outside.

Proceeding from a high-resistivity semiconductor body, the described embodiment can be obtained by the deposition of a doping grid, for example by ion implantation and the addition of the grid disposed vertically thereover by conventional in-diffusion behind masks, the epitaxial growth of a layer whose height roughly corresponds to the height of the hillocks, and structural etching. The aforesaid ion implantation can also be replaced by conventional in-diffusion behind masks.

Semiconductor materials that can be contemplated for use in semiconductor optical radiation sources according to both the first and the second exemplary embodiment are, for example, GaP and silicon-doped GaAs.

To keep material consumption low and to ensure that the hillocks can be produced in a relatively simple manner, the heights of the hillocks are provided to be about 30 μm. Such low hillock heights also ensure that absorption of the generated radiation in the semiconductor crystal will be minimal, since the path traveled in the semiconductor is correspondingly short.

17 claims

3 figures

Claims

1. A semiconductor optical radiation source comprising at least one pn junction between two regions of different types of conductivity, characterized in that at least one of the two semiconductor regions has a hilly outer surface.

2. The semiconductor optical radiation source as recited in claim 1, characterized in that the hillocks are realized as specific geometrical, spatial figures.

3. The semiconductor optical radiation source as recited in claims 1 and 2, characterized in that said hillocks have an approximately triangular cross section.

4. The semiconductor optical radiation source as recited in claim 3, characterized in that the angle of said triangular cross section that is at the peaks of said hillocks is approximately twice the critical angle of total reflection of the material forming said hillocks.

5. The semiconductor optical radiation source as recited in claim 3 and/or 4, characterized in that said hillocks are pyramidal or conical in shape.

6. The semiconductor optical radiation source as recited in claim 1 and/or 2, characterized in that said hillocks are circular or parabolic in cross section.

7. The semiconductor optical radiation source as recited in claim 6, characterized in that said hillocks are formed to be hemispherical or paraboloid.

8. The semiconductor optical radiation source as recited in one of claims 1 to 5, characterized in that the pn junction layers emitting the optical radiation are disposed inside said hillocks.

9. The semiconductor optical radiation source as recited in claim 8, characterized in that the radiation-generating pn junction layers are disposed in the upper third of each said hillock.

10. The semiconductor optical radiation source as recited in one of claims 1 to 7, characterized in that the pn junction layers emitting the radiation are disposed under said hillocks.

11. The semiconductor optical radiation source as recited in one of claims 1 to 10, characterized in that said pn junction layers emitting said optical radiation are narrower than the widest portions of said hillocks.

12. The semiconductor optical radiation source as recited in claim 11, characterized in that the diameter of each pn junction layer is less than 30% of the smallest width of the hillock concerned.

13. The semiconductor optical radiation source as recited in one of claims 1 to 12, characterized in that said pn junction layers emitting said optical radiation are disposed concentrically with the centers of said hillocks.

14. The semiconductor optical radiation source as recited in one of claims 1 to 13, characterized in that said hillocks form rows of hillocks.

15. The semiconductor optical radiation source as recited in as recited in claim 13, characterized in that said rows of hillocks extend in a wave-shaped or meander-shaped manner.

16. The semiconductor optical radiation source as recited in one of claims 1 to 15, characterized in that the valleys between said hillocks are filled with a transparent medium that has a refractive index greater than 1.5.

17. A method of fabricating a semiconductor optical radiation source according to one of claims 1 to 7 and 10 to 16, characterized in that arranged in a high-resistivity semiconductor body are plural parallel, stripe-shaped regions of one type of conductivity and, thereover and approximately perpendicularly thereto, plural parallel, stripe-shaped regions of a second type of conductivity opposite to said first type of conductivity, and in that the areas of intersection of the two regions of different types of conductivity come to be disposed under the centers of said hillocks.

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Fig.1

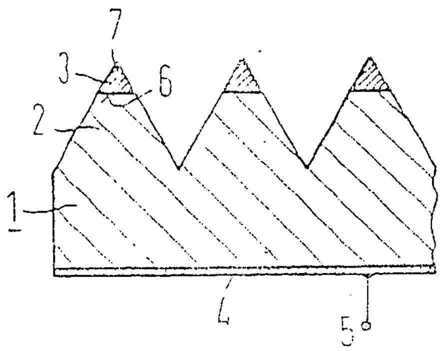

Fig.2

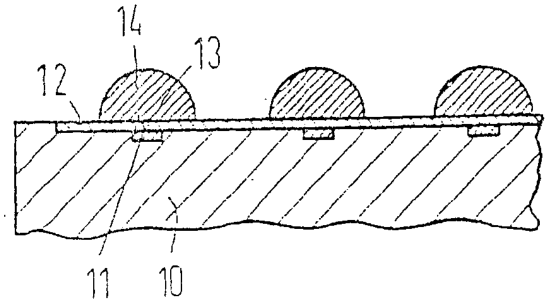

Fig.3